



Organic-Tainted Mineral Soils, Part I: Defining Geotechnical Treatability Through Neutralisation Demand

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ABSTRACT

Organic-tainted mineral soil (OTMS) is an under-recognised subgrade condition between conventional mineral soil and peat. Although mineral-dominated and physically workable, its reactive organic fraction may consume alkalinity, sequester calcium, passivate mineral surfaces and suppress durable cementitious bonding. Conventional lime- or cement-only treatment may therefore produce delayed, spatially variable and moisture-sensitive strength despite satisfactory dry laboratory results. This critical review delineates the geotechnical territory of OTMS and advances neutralisation demand as the governing variable for treatability. It denotes the minimum chemical input required to overcome organic acidity and buffering, satisfy initial calcium uptake and establish a sustained pore-fluid environment favourable to binder hydration. Evidence synthesised from cement-, lime- and alternative cementation systems shows that stabilisation depends not only on organic quantity, but also on organic reactivity, calcium availability, alkalinity retention, mineralogy and pore-fluid chemistry. The proposed framework distinguishes the treatment consumed in controlling organic interference from the binder capacity remaining to develop engineering strength. It further identifies an optimum chemical window: insufficient treatment leaves the organic demand unresolved, whereas excessive alkalinity or calcium addition may induce adverse pore-structural and volumetric effects. OTMS treatability should therefore be evaluated through mechanism-based chemical compatibility rather than fixed organic thresholds or empirical binder escalation. The framework provides a testable basis for subsequent laboratory determination of neutralisation demand, engineering-performance verification and field-scale assessment. As a critical review and conceptual framework, this Part I reports no new laboratory or field validation data.

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1. INTRODUCTION

Road construction over weak and chemically variable subgrade requires more than increased binder dosage; it demands a treatment strategy that delivers uniform, moisture-resistant and mechanically reliable support. Cement, lime and blended binders can improve strength, stiffness, compaction and bearing capacity while reducing excavation and imported fill. Their effectiveness, however, depends on sustained soil-binder cementation. Malaysian specifications provide contextual performance requirements for stabilisation,

compaction and soaked California Bearing Ratio; they are cited here to establish the road-engineering context and are not presented as evidence that OTMS has satisfied those requirements [1], [2].

A critical but often overlooked problem arises in compactable mineral soils containing moderate quantities of reactive organic matter. Common in agricultural land, shallow alluvium, drainage corridors and heterogeneous fill, these soils may exhibit delayed strength gain, poor binder efficiency and

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high moisture sensitivity. Humic and fulvic substances consume alkalinity, complex calcium and adsorb onto mineral and cement surfaces, suppressing pozzolanic reactions and C-S-H- and C-A-H-type bonding. Organic-induced strength loss has been reported by Du et al. [3], while Kang et al. [4] identified curing-related disruption in cement-treated clay. Further evidence confirms that organic reactivity, rather than total content alone, governs stabilisation response [5], [6].

This paper defines organic-tainted mineral soil (OTMS) and develops a neutralisation-first framework that separates the chemical demand imposed by reactive organic matter from the subsequent structural function of cementitious treatment. As a critical review, Part I reports no new laboratory or field validation data. Its purpose is to establish the mechanistic basis

of OTMS treatability, define neutralisation demand and delimit the chemical treatment window that subsequent experimental and field studies can test.

2. THE INTERMEDIATE GROUND CATEGORY

The geotechnical boundary of organic-tainted mineral soil (OTMS) must be clearly distinguished from both conventional mineral subgrade and unsuitable organic ground. Routine earthwork assessment commonly separates usable mineral soils from topsoil, peat, highly organic deposits and excessively soft materials. This binary approach may overlook an intermediate condition: Mineral-dominated, physically compactable soil containing sufficient reactive organic matter to impair stabilisation (Figure 1).

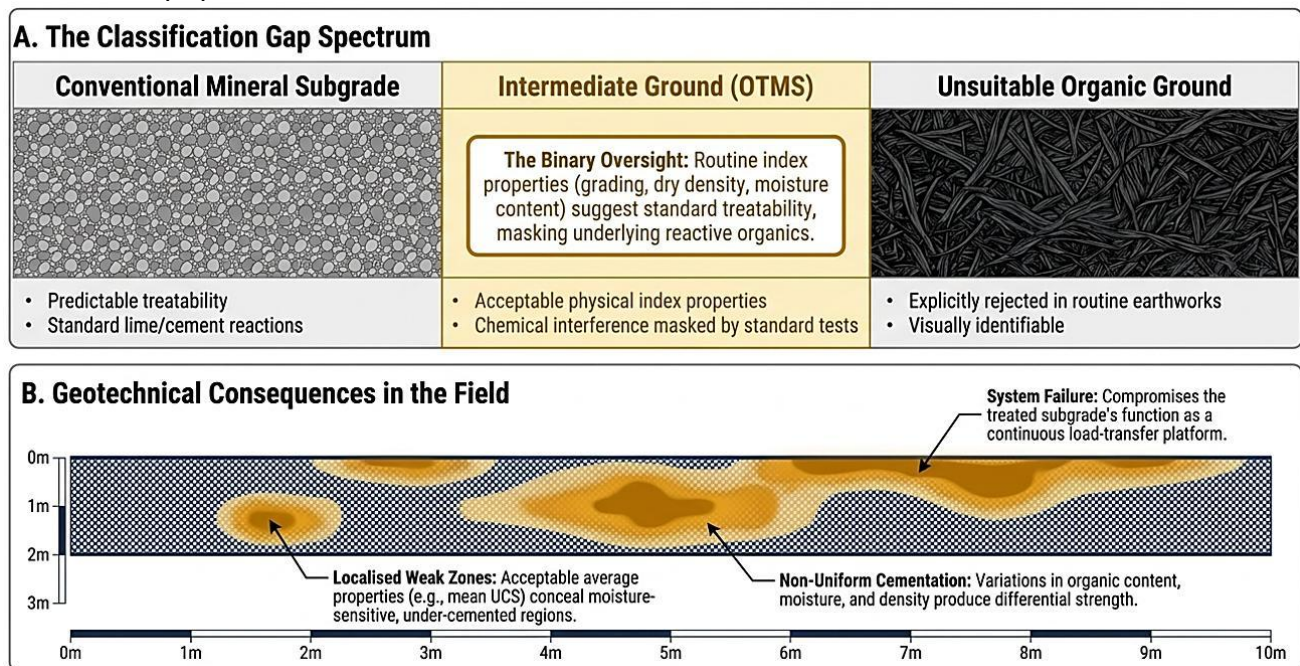


Fig. 1. The Intermediate Ground Theory illustrating (A) comparison of conventional and OTMS domain assessment, and (B) negative geotechnical implications from organic heterogeneity.

OTMS may retain a recognisable sand-silt-clay grading, measurable maximum dry density and optimum moisture content, and an apparently coherent mineral fabric. These properties can suggest that lime or cement treatment is feasible. Yet the organic fraction may alter water retention, pore-fluid chemistry, interparticle contact and binder-mineral interaction without materially changing visual appearance or routine index properties. Shao et al. [6] showed that different organic constituents produce distinct effects on strength, deformation and soil structure, confirming that total organic content alone cannot predict stabilisation response.

Such soils may arise from topsoil intrusion, decomposed root matter, organic-bearing alluvium, floodplain deposits, drainage corridors or contaminated excavated fill. Although far less organic than peat, they may still exhibit delayed hardening, reduced shear strength, poor stiffness recovery and high binder sensitivity. Konkol and Tisler [7] demonstrated that calcium availability markedly altered the response of stabilised organic silt, underscoring the importance of binder chemistry.

For road infrastructure, this variability is critical because the treated subgrade must function as a continuous load-transfer platform. Local changes in organic content, moisture,

mineralogy and treatment depth may create weak zones despite acceptable average properties. Huang et al. [8] similarly linked higher humic-acid content to weaker particle contacts, greater porosity and reduced cemented strength.

OTMS should therefore be regarded as a geotechnical treatability domain requiring targeted chemical conditioning before reliable structural cementation can occur.

3. DISTINCTION FROM PEAT AND HIGHLY ORGANIC DEPOSITS

OTMS is not a substitute label for peat. Peat is organic-dominated, highly compressible and typically characterised by fibrous fabric, very high water content, low dry density and poor bearing capacity. Its response is governed largely by consolidation and creep, such that embankment performance may remain settlement-controlled despite local strength improvement. Siddiqua et al. [9] further showed that organic deposits can vary markedly in strength, stiffness and compressibility.

By contrast, OTMS remains mineral-dominated, exhibits a conventional moisture-density response and occurs within a shallow, workable layer suitable for in-situ treatment. Its principal limitation is chemical interference with binder hydration rather than deformation of a thick organic deposit. The material must also retain a credible prospect of meeting compaction, soaked bearing capacity, stiffness and durability requirements. This distinction is essential because chemical hardening cannot eliminate foundation-scale deformation. Peat behaviour remains closely linked to compressibility and fabric [10], while mass-stabilised organic clay is influenced jointly by binder dosage, preload and final porosity [11].

Accordingly, deposits governed by fibrous structure, excessive moisture or deep compression fall outside the OTMS framework and require deeper ground-improvement solutions. OTMS is therefore a geotechnical treatability category for shallow mineral soils requiring pretreatment before reliable cementation.

4. ORGANIC QUANTITY DOES NOT DEFINE ORGANIC INTERFERENCE

OTMS treatability cannot be determined by organic percentage alone. Loss on ignition and total organic carbon quantify the organic fraction but do not reveal its chemical form, reactivity or effect on binder hydration. Tremblay et al. [12] showed that soils with similar organic contents may develop markedly different cemented strengths because their organic compounds interact differently with stabilisers. Organic content is therefore a screening indicator, not a definitive treatment criterion.

Humic and fulvic substances are especially disruptive because they promote acidification, surface adsorption and calcium complexation. Wang et al. [13] linked fulvic-acid-induced strength loss to these combined mechanisms, while Luo and Zhang [14] confirmed that geopolymer binders also

remain vulnerable. The controlling factor is thus the chemical demand imposed on the soil-binder system. A modest concentration of highly reactive organics may consume more alkalinity, immobilise more calcium and retard cementation more severely than a larger quantity of relatively inert residue. Calcium-mediated sorption further reduces the calcium available for C-S-H- and C-A-H-type formation [15].

Mineralogy compounds this variability because clay type, surface area, charge and cation-exchange capacity govern organic adsorption and binder accessibility [16]. OTMS assessment should therefore integrate organic reactivity, equilibrated pH, buffering capacity, calcium demand, mineralogy, moisture, binder chemistry and curing. As Zhao and Wong [17] emphasised, cement-soil behaviour reflects interacting material and process variables. The treatment boundary should consequently be defined by the onset of measurable binder inefficiency, providing the basis for determining neutralisation demand before binder selection.

5. GEOTECHNICAL CONSEQUENCES AND THE CLASSIFICATION-TREATMENT GAP

The chemical variability of OTMS affects the full stabilisation cycle. During construction, elevated moisture demand, poor pulverisation and irregular compaction may combine with variations in organic content, density and treatment depth to produce non-uniform cementation. As illustrated in Figure 2, conventional mineral soils generally permit direct binder-mineral interaction, whereas OTMS introduce coupled chemical and physical disruptions that restrict hydration, particle bonding and strength development. Ackah et al. [18] showed that subgrade strength depends jointly on moisture content, dry density, binder dosage and curing; in OTMS, organic heterogeneity adds another source of uncertainty, allowing acceptable mean values to conceal localised weak zones.

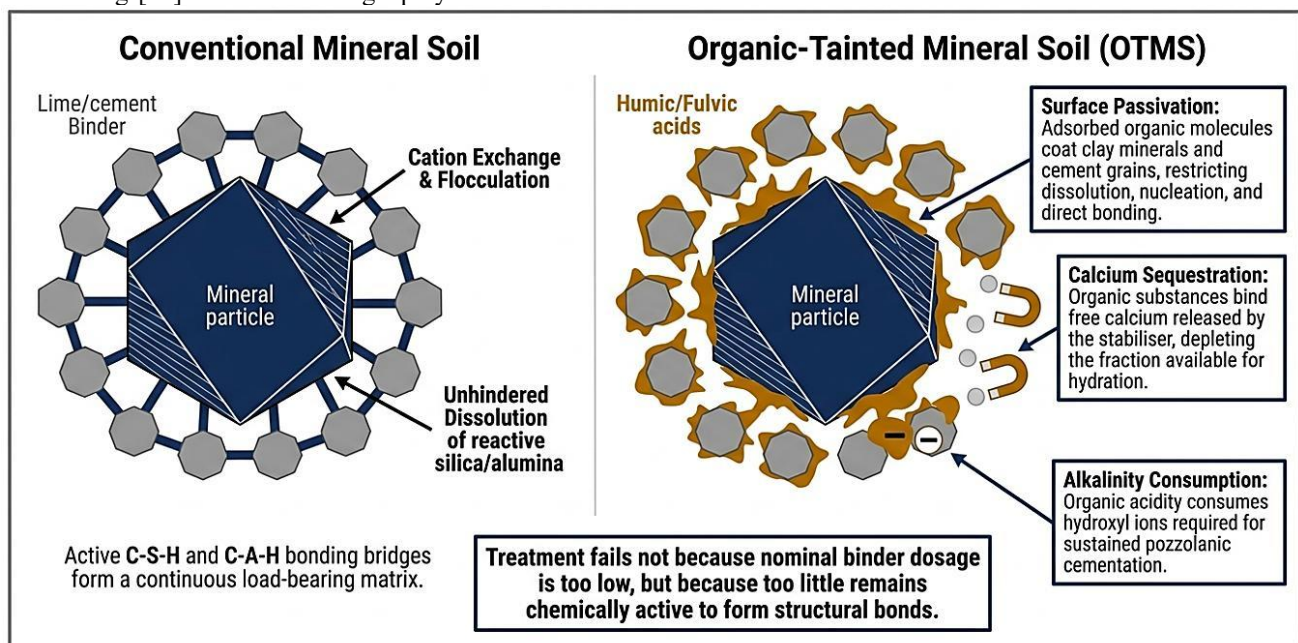


Fig. 2. Coupled Mechanistic Disruption in OTMS Stabilisation - comparison between conventional mineral soils and OTMS.

During curing, OTMS may develop delayed setting, incomplete particle bonding and high residual porosity.

Increasing cement dosage can improve average UCS without eliminating under-cemented or moisture-sensitive regions. This

is critical because stabilised subgrade performs under repeated traffic and fluctuating moisture rather than dry monotonic loading. Wetting-drying cycles can weaken cementitious bonds, modify pore structure and reduce resilient modulus, as demonstrated by Hoy et al. [19] and Owusu et al. [20]. Prolonged fulvic-acid exposure may also promote decalcification and connected porosity, allowing organic interference to persist as a durability mechanism [21]. The consequences include reduced soaked CBR, stiffness loss, pumping, permanent deformation, differential support, rutting and cracking. Assessment should therefore extend beyond dry UCS to soaked CBR, resilient modulus, moisture durability, volumetric stability and treatment uniformity, supported by realistic field validation, as emphasised by Syed et al. [22].

These risks expose a critical gap between soil classification and binder design. Routine testing may identify OTMS as mineral-dominated and quantify organic content, yet it cannot establish whether the organic fraction will consume alkalinity, complex calcium or inhibit long-term cementation. Conversely, failure of cement-only treatment may reflect unresolved chemical demand rather than intrinsic untreatability. The OTMS framework therefore introduces a formal chemical-treatability stage before structural stabilisation. Treatment should proceed only where the soil remains workable, organic interference can be quantified, practical neutralisation demand established, binder-compatible alkalinity sustained and durable cementation verified. The central question thus shifts from how much cement is required to what chemical condition must first be created for reliable cementation.

6. MECHANISTIC BASIS OF NEUTRALISATION DEMAND

OTMS cannot be treated simply as weak soil requiring more binder. Its behaviour is governed by interactions among the mineral skeleton, reactive organics and pore fluid, which determine how much stabiliser remains available for cementation. The paper therefore distinguishes two functions: (1) Satisfying the organic chemical demand, and (2) developing the cementitious structure required for durable geotechnical performance.

6.1 Coupled Disruption of Cementitious Strengthening

In conventional mineral soil, cement hydration forms calcium silicate hydrate and calcium aluminate hydrate phases that fill pores, bridge particles and increase stiffness and strength. Lime promotes cation exchange and flocculation, while sustained alkalinity dissolves reactive silica and alumina for longer-term pozzolanic cementation. Both mechanisms depend on available calcium, sufficient hydroxyl ions, accessible mineral surfaces, moisture and favourable curing conditions.

Reactive organic matter disrupts these requirements concurrently. Carboxylic and phenolic groups in humic substances bind calcium, organic acidity consumes hydroxyl ions, and adsorbed organics coat clay minerals and cement grains, restricting dissolution, nucleation and bonding. Harvey et al. [23] linked natural organic matter to reduced C-S-H formation in lime-stabilised smectite, while Ma et al. [24] showed that humic acid suppressed hydration-product development and consumed part of the binder capacity. The impairment may also persist beyond early curing: Joy et al. [25]

observed limited later strength development as pH declined, and Chen et al. [26] found progressively inhibited calcium-carbonate precipitation with increasing humic-acid concentration.

Organic interference should therefore be understood as a coupled chemical demand involving calcium binding, alkalinity consumption, surface passivation and water retention. Delayed hardening does not necessarily indicate eventual complete cementation; strength development may cease once the chemical environment can no longer sustain binder reactions. Conventional treatment may consequently fail not because the nominal binder dosage is too low, but because too little remains chemically active to develop a continuous, durable load-bearing matrix.

6.2 Neutralisation Demand as the Governing Design Variable

This paper advances neutralisation demand as the central variable governing OTMS treatability. It denotes the minimum chemical input required to overcome organic acidity and buffering, satisfy initial calcium sequestration and establish a sustained pore-fluid environment favourable to binder hydration. Engineering performance is used subsequently to verify whether treatment is geotechnically effective; it is not part of the chemical definition of neutralisation demand itself. The concept separates the treatment consumed by organic interference from that remaining to develop cementitious bonding and engineering strength. As conceptualised in Figure 3, OTMS treatment therefore involves a two-stage chemical transition: initial consumption of the organic neutralisation demand, followed by structural cementation within an optimum chemical window bounded by insufficient treatment and deterioration. Supporting this distinction, Ma et al. [27] quantified increasing stabiliser consumption in humic-acid-bearing clay, showing that part of the treatment may be depleted before effective cementation begins.

Neutralisation demand extends beyond total organic content and immediate pH. Loss on ignition and total organic carbon quantify organic matter but do not indicate its acidity, calcium-binding capacity or ability to passivate reactive surfaces. In Ariake clay, humic acid suppressed pozzolanic-product formation and reduced the strength of lime-treated soil, whereas increased salt concentration moderated this interference [28]. Mohd Yunus et al. [29] similarly observed marked deterioration beyond a material-specific humic-acid threshold, demonstrating that stabilisation may decline disproportionately once organic demand exceeds the available chemical capacity.

A high initial pH confirms only temporary alkalinity; it does not establish whether the condition will persist after equilibration or whether sufficient reactive calcium remains available. Part I intentionally does not prescribe a universal target pH, equilibration period, water-to-solid ratio or conditioning-dose increment because these parameters require empirical calibration for the specific soil-conditioner-binder system. Establishing such values constitutes a subsequent method-development step rather than a prerequisite for defining the mechanistic concept of neutralisation demand. Candidate conditioners may include lime-based or other alkaline and calcium-bearing systems capable of addressing the dominant acidity, buffering or calcium demand.

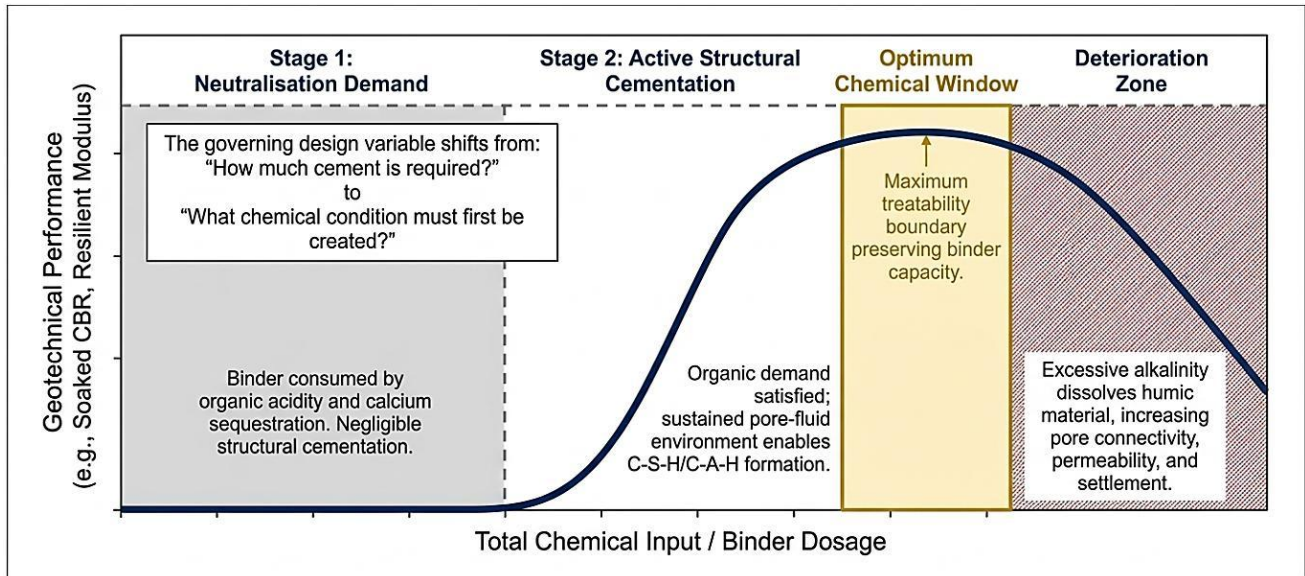


Fig. 3. The Neutralisation Demand Framework for OTMS - a two-stage chemical transition involving (1) organic demand consumption and (2) structural cementation bound by an optimum chemical window and deterioration zone.

Selection should be governed by compatibility with the soil chemistry, environmental acceptability, local availability, handling requirements and project-specific cost rather than by a universal prescribed agent or dosage. For instance, Cao et al. [21] found that ultra-fine cement improved hydration-product formation and reduced macroporosity in humic-acid-containing soil, but the benefit diminished beyond the optimum dosage. Greater binder reactivity may therefore offset organic interference without resolving its underlying chemical demand.

6.3 Optimum Chemical Window and Treatability Boundary

Neutralisation must not be equated with maximising alkalinity or calcium addition. Zhang et al. [30] showed that strongly alkaline conditions can promote cementitious-phase formation while simultaneously dissolving humic material, increasing pore connectivity, permeability and settlement. Horpibulsuk et al. [31] identified a comparable dosage boundary in calcium-carbide-residue-fly-ash stabilisation, where strength development progressed through active, inert and deterioration zones. Calcium-rich treatment therefore operates within an optimum chemical window rather than improving continuously with dosage.

Joy et al. [32] demonstrated this dosage sensitivity in lime-treated organic-rich marine clay. Moderate sodium-chloride addition improved calcium availability, particle interaction and long-term strength, whereas a higher dosage induced dispersion and restricted hydration. Although the reported dosages are not transferable directly to OTMS, the case confirms that effective conditioning is material-specific and governed by competing beneficial and adverse reactions. The treatability boundary shown in Figure 3 consequently represents the point beyond which additional chemical input no longer produces proportional geotechnical benefit and may instead initiate deterioration.

Neutralisation demand consequently offers a more defensible treatment basis than fixed organic thresholds or empirical binder escalation. It determines whether organic interference can be controlled at a practical dosage without causing adverse pore-structural, volumetric or environmental effects, while preserving sufficient binder capacity for durable

cementation. Soils requiring excessive treatment, failing to sustain binder-compatible chemistry or remaining governed by deep compressibility and decomposition fall outside the framework. The governing question therefore shifts from how much binder should be added to what chemical condition must first be established for reliable geotechnical performance.

Environmental compatibility also constrains the upper treatability boundary. Neutralisation-first treatment does not justify unrestricted alkaline addition. Before field application, candidate conditioners should be screened for leachability and the potential migration of high-pH pore water and dissolved ions, mobilisation of dissolved organic matter or trace constituents, proximity to groundwater, and relevant drainage or runoff pathways. Because the present conceptual review generates no leaching or groundwater dataset, these considerations are identified as environmental screening requirements rather than quantified environmental impacts.

7. CONCLUSION

This paper establishes OTMS as a distinct geotechnical treatability category between conventional mineral soil and peat, defined by mineral-dominated behaviour but constrained by reactive organic interference with binder chemistry. The central contribution is the identification of neutralisation demand as the governing variable linking organic reactivity to stabilisation efficiency, moving treatment design beyond organic-content thresholds and empirical binder escalation. OTMS remains treatable only where chemical interference can be controlled within a practical conditioning range while preserving sufficient capacity for durable cementation; soils requiring excessive treatment or governed by deep compressibility, decomposition or persistent moisture instability fall outside this boundary. This conceptual framework therefore defines what OTMS is, why conventional stabilisation may fail, and where shallow treatment remains geotechnically defensible. This conceptual framework therefore defines what OTMS is, explains why conventional stabilisation may fail, and identifies where shallow chemical treatment remains geotechnically defensible, while providing a

testable basis for subsequent laboratory and field studies. No empirical validation is claimed in Part I.

REFERENCES

- [1] Jabatan Kerja Raya Malaysia, *Standard specification for road works: Section 18-Soil stabilisation (JKR/SPJ/2018-S18)*, Malaysia, 2018. url: <https://www.scribd.com/document/650982976/18-SPJ-S18-SOIL-STABILISATION>
- [2] Jabatan Kerja Raya Malaysia, *Standard specification for road works: Section 2-Earthworks (JKR/SPJ/2020-S2)*, Malaysia, 2020. url: <https://stom.melaka.gov.my/notices/9419/file/44167>
- [3] C. Du, J. Zhang, G. Yang, and Q. Yang, "The influence of organic matter on the strength development of cement-stabilized marine soft clay," *Marine Georesources & Geotechnology*, vol. 39, no. 8, pp. 983-993, 2021. doi: <https://doi.org/10.1080/1064119X.2020.1792593>
- [4] G.-O. Kang, T. Tsuchida, Y.-S. Kim, and W.-J. Baek, "Influence of humic acid on the strength behavior of cement-treated clay during various curing stages," *Journal of Materials in Civil Engineering*, vol. 29, no. 8, Art. no. 04017057, 2017. doi: [https://doi.org/10.1061/\(ASCE\)MT.1943-5533.0001919](https://doi.org/10.1061/(ASCE)MT.1943-5533.0001919)
- [5] L. Lang, N. Liu, and B. Chen, "Strength development of solidified dredged sludge containing humic acid with cement, lime and nano-SiO₂," *Construction and Building Materials*, vol. 230, Art. no. 116971, 2020. doi: <https://doi.org/10.1016/j.conbuildmat.2019.116971>
- [6] L. Shao, Z. Ding, S. Wang, K. Pan, and C. Hu, "Effect of organic matter components on the mechanical properties of cemented soil," *Materials*, vol. 16, no. 17, Art. no. 5889, 2023. doi: <https://doi.org/10.3390/ma16175889>
- [7] J. Konkol and W. Tisler, "Engineering properties of submerged organic silt stabilized with F-class fly ash," *Journal of Rock Mechanics and Geotechnical Engineering*, vol. 17, no. 8, pp. 5334-5347, 2025. doi: <https://doi.org/10.1016/j.jrmge.2025.03.058>
- [8] S. Huang et al., "Study on microstructure of cemented organic soil in Dianchi Lake, China," *Applied Sciences*, vol. 13, no. 3, Art. no. 1825, 2023. doi: <https://doi.org/10.3390/app13031825>
- [9] S. Siddiqua, A. ElMouchi, and D. Wijewickreme, "Characterization of an organic soil deposit using multi-faceted geotechnical field and laboratory investigations," *Engineering Geology*, vol. 328, Art. no. 107365, 2024. doi: <https://doi.org/10.1016/j.enggeo.2023.107365>
- [10] F. A. Abdul Azam, R. Che Omar, R. Roslan, I. N. Z. Baharudin, and M. Z. Razman, "Mechanical behaviour, compressibility, and microstructural analysis of problematic soil through a green soil stabilization approach," *Results in Engineering*, vol. 24, Art. no. 103524, 2024. doi: <https://doi.org/10.1016/j.rineng.2024.103524>
- [11] V. Núñez, A. Lotero, C. A. Bastos, and N. C. Consoli, "Controlling the mechanical behavior of mass-stabilized organic clay with various binders," *Geotechnical and Geological Engineering*, vol. 43, Art. no. 54, 2025. doi: <https://doi.org/10.1007/s10706-024-03049-z>
- [12] H. Tremblay, J. Duchesne, J. Locat, and S. Leroueil, "Influence of the nature of organic compounds on fine soil stabilization with cement," *Canadian Geotechnical Journal*, vol. 39, no. 3, pp. 535-546, 2002. doi: <https://doi.org/10.1139/t02-002>
- [13] S. Wang et al., "Influence mechanism of fulvic acid on the strength of cement-solidified dredged sludge," *Water*, vol. 14, no. 17, Art. no. 2616, 2022. doi: <https://doi.org/10.3390/w14172616>
- [14] Z. Luo and B. Zhang, "Effect of humic acid and fulvic acid on mechanical and durability properties of geopolymer-stabilized soft soil," *Construction and Building Materials*, vol. 409, Art. no. 133875, 2023. doi: <https://doi.org/10.1016/j.conbuildmat.2023.133875>
- [15] I. A. Shabtai et al., "Calcium promotes persistent soil organic matter by altering microbial transformation of plant litter," *Nature Communications*, vol. 14, Art. no. 6609, 2023. doi: <https://doi.org/10.1038/s41467-023-42291-6>
- [16] J. Calero, R. García-Ruiz, M. Torrús-Castillo, J. L. Vicente-Vicente, and J. M. Martín-García, "Role of clay mineralogy in the stabilization of soil organic carbon in olive groves under contrasted soil management," *Minerals*, vol. 13, no. 1, Art. no. 60, 2023. doi: <https://doi.org/10.3390/min13010060>
- [17] K. Zhao and L. N. Y. Wong, "A review of cement-soil in engineering geological applications: Mixing mechanisms, mechanical behavior, and constitutive models," *Bulletin of Engineering Geology and the Environment*, vol. 84, Art. no. 637, 2025. doi: <https://doi.org/10.1007/s10064-025-04659-4>
- [18] F. S. Ackah, R. Owusu, Y. Xiao, and J. Ali, "Prediction and optimization of electrical resistivity and unconfined compressive strength of cement-treated subgrade soil using I-optimal response surface methodology," *Engineering Science and Technology, an International Journal*, vol. 60, Art. no. 101878, 2024. doi: <https://doi.org/10.1016/j.jestech.2024.101878>
- [19] M. Hoy et al., "Wetting-drying durability performance of cement-stabilized recycled materials and lateritic soil using natural rubber latex," *Construction and Building Materials*, vol. 403, Art. no. 133108, 2023. doi: <https://doi.org/10.1016/j.conbuildmat.2023.133108>
- [20] R. Owusu, F. S. Ackah, and Y. Xiao, "Effect of wetting and drying cycles on resilient modulus and microstructure characteristics of heterogeneous quicklime-stabilized subgrade," *Case Studies in Construction Materials*, vol. 22, Art. no. e04009, 2025. doi: <https://doi.org/10.1016/j.cscm.2024.e04009>
- [21] J. Cao et al., "Experimental study on the corrosion of fulvic acid to cement-soil and its microstructures in the peat soil environment," *Coatings*, vol. 13, no. 8, Art. no. 1366, 2023. doi: <https://doi.org/10.3390/coatings13081366>
- [22] M. Syed, A. GuhaRay, and S. Raju, "Subgrade strength performance behavior of alkali-activated binder and cement stabilized expansive soil: A semifiel study," *ASCE Journal of Materials in Civil Engineering*, vol. 35, no. 10, Art. no. 04023329, 2023. doi: <https://doi.org/10.1061/JMCEE7.MTENG-15580>
- [23] O. R. Harvey, J. P. Harris, B. E. Herbert, E. A. Stiffler, and S. P. Haney, "Natural organic matter and the formation of calcium-silicate-hydrates in lime-stabilized smectites: A thermal analysis study," *Thermochimica Acta*, vol. 505, nos. 1-2, pp. 106-113, 2010. doi: <https://doi.org/10.1016/j.tca.2010.04.007>
- [24] C. Ma, B. Chen, and L. Chen, "Effect of organic matter on strength development of self-compacting earth-based construction stabilized with cement-based composites," *Construction and Building Materials*, vol. 123, pp. 414-423, 2016. doi: <https://doi.org/10.1016/j.conbuildmat.2016.07.018>
- [25] A. Joy, B. M. Abraham, and A. Sridharan, "Effect of organic matter on the shear strength of lime-stabilised clayey soils," *Proceedings of the Institution of Civil Engineers-Ground Improvement*, vol. 176, no. 2, pp. 99-107, 2023. doi: <https://doi.org/10.1680/jgrim.20.00055>
- [26] M. Chen et al., "Effect of humic acid on soil solidification by enzyme-induced carbonate precipitation," *Biogeotechnics*, vol. 3, no. 4, Art. no. 100133, 2025. doi: <https://doi.org/10.1016/j.bgttech.2024.100133>
- [27] C. Ma, B. Zhao, G. Long, X. Sang, and Y. Xie, "Quantitative study on strength development of earth-based construction prepared by organic clay and high-efficiency soil stabilizer," *Construction and Building Materials*, vol. 174, pp. 520-528, 2018. doi: <https://doi.org/10.1016/j.conbuildmat.2018.04.119>
- [28] K. Onitsuka, C. Modmoltin, M. Kouno, and T. Negami, "Effect of organic matter on lime and cement stabilized Ariake clays," *Doboku Gakkai Ronbunshu*, no. 729, pp. 1-13, 2003. doi: https://doi.org/10.2208/jscej.2003.729_1
- [29] N. Z. Mohd Yunus, D. Wanatowski, and L. R. Stace, "Lime stabilisation of organic clay and the effects of humic acid content," *Geotechnical Engineering Journal of the SEAGS & AGSSEA*, vol. 44, no. 1, pp. 19-25, 2013. doi: <https://doi.org/10.14456/seagj.2013.33>
- [30] Y. Zhang et al., "Cement-induced alkaline environment on organic soil: Deterioration, compensation, and the microstructure-mechanical property relationship," *Applied Sciences*, vol. 16, no. 9, Art. no. 4324, 2026. doi: <https://doi.org/10.3390/app16094324>
- [31] S. Horpibulsuk, C. Phetchuay, A. Chinkulkijniwat, and A. Cholphatsorn, "Strength development in silty clay stabilized with calcium carbide residue and fly ash," *Soils and Foundations*, vol. 53, no. 4, pp. 477-486, 2013. doi: <https://doi.org/10.1016/j.sandf.2013.06.001>
- [32] A. Joy, B. M. Abraham, and A. Sridharan, "Optimizing lime stabilization of organic-rich marine clay with sodium chloride," *Discover Soil*, vol. 2, Art. no. 102, 2025. doi: <https://doi.org/10.1007/s44378-025-00134-4>